The Growing Significance of Renewable Energy

Presented at New Mexico State University

February 23, 2007

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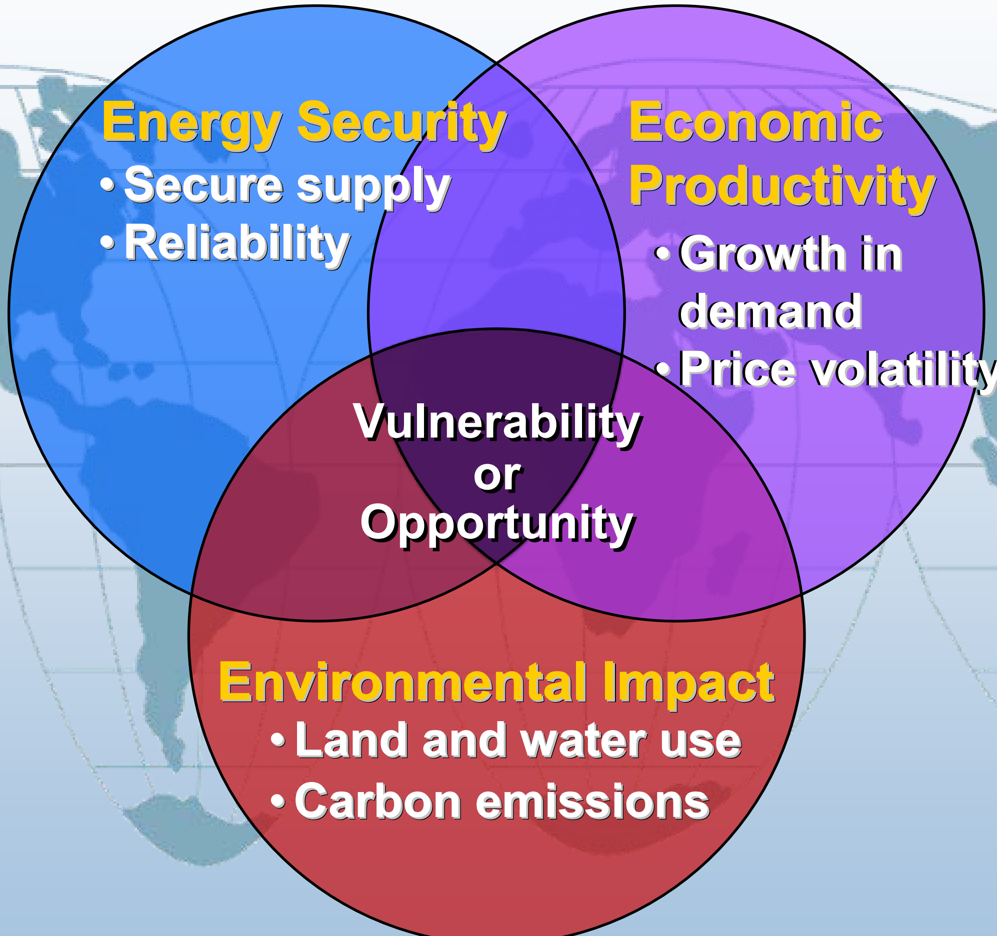
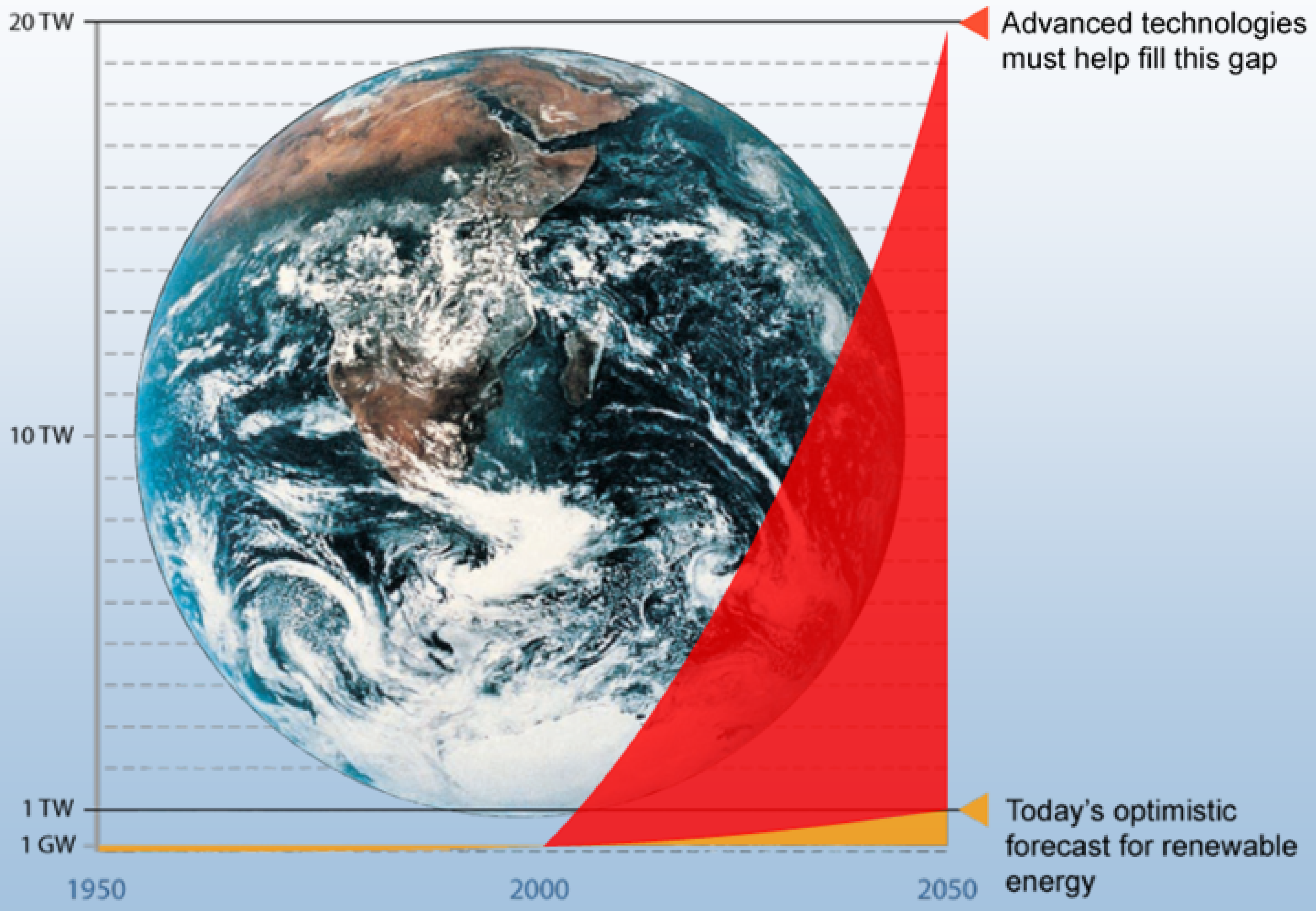
Energy Solutions Are Enormously Challenging



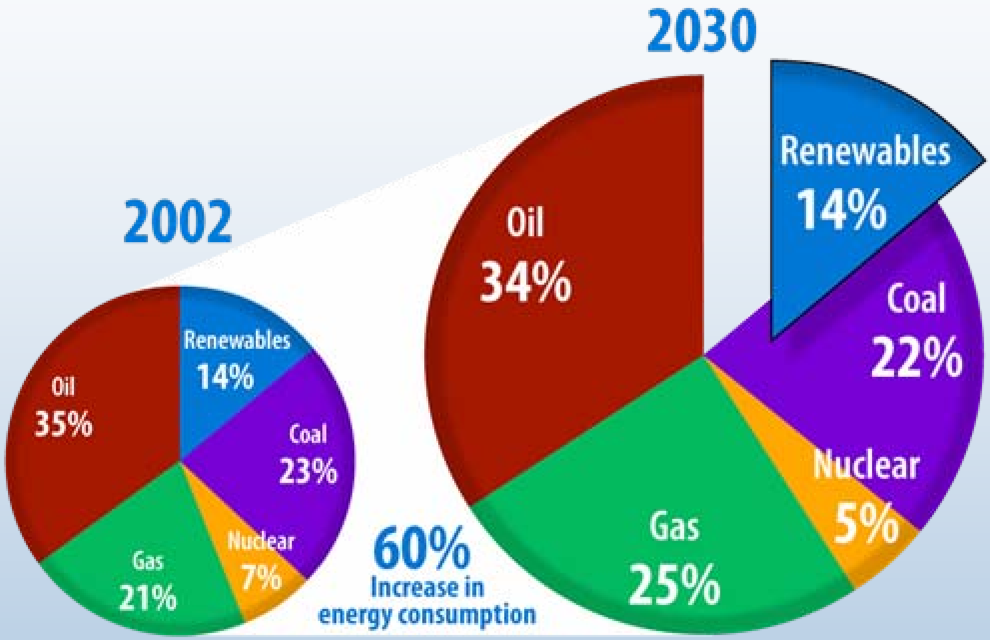
Must address all three imperatives

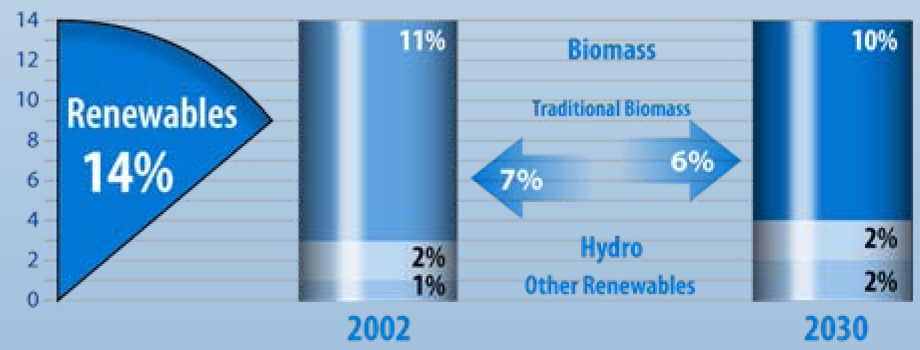
How Big is the Challenge?



Source: Arvizu, NREL

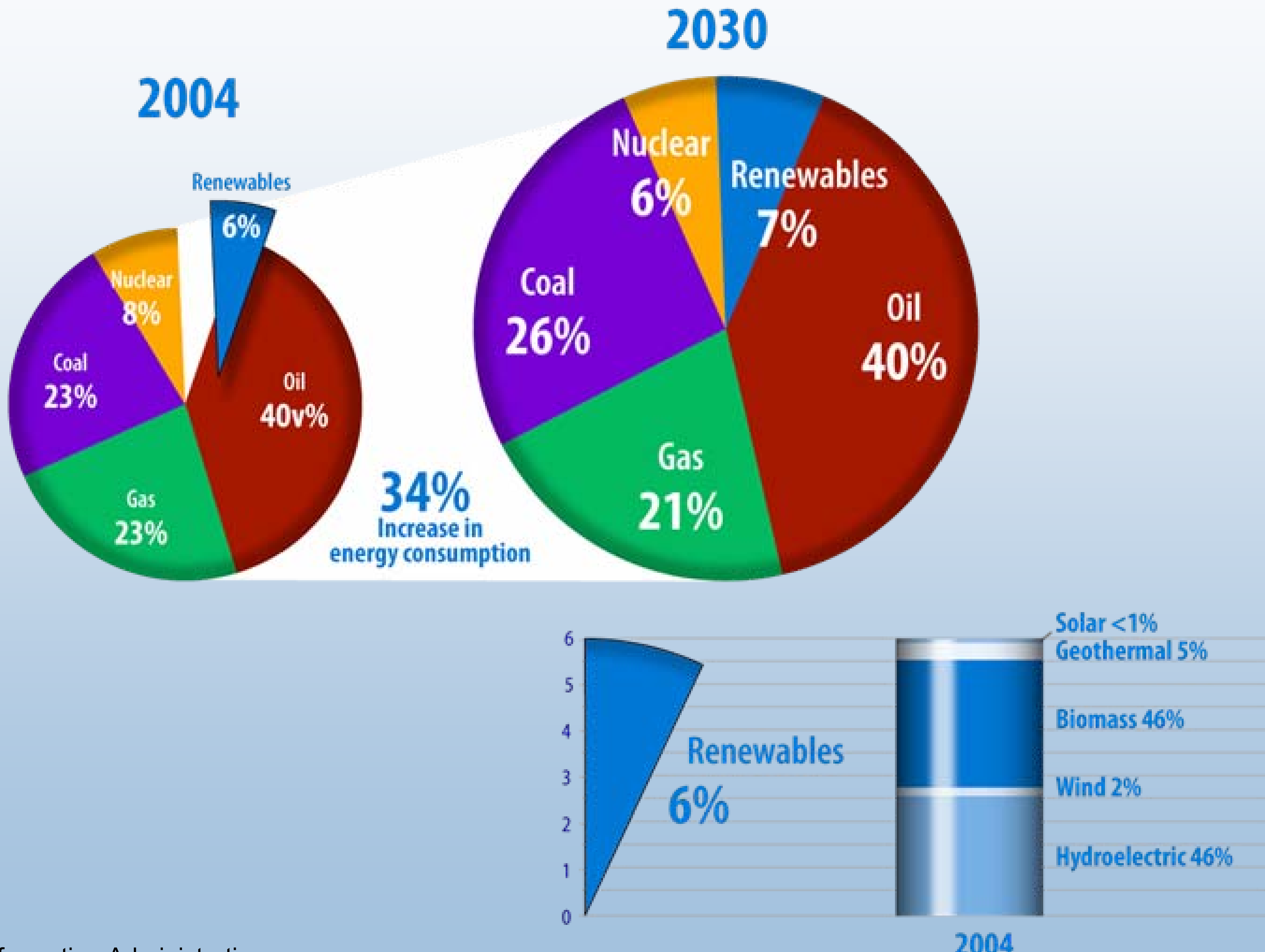
World Energy Supply and the Role of Renewable Energy





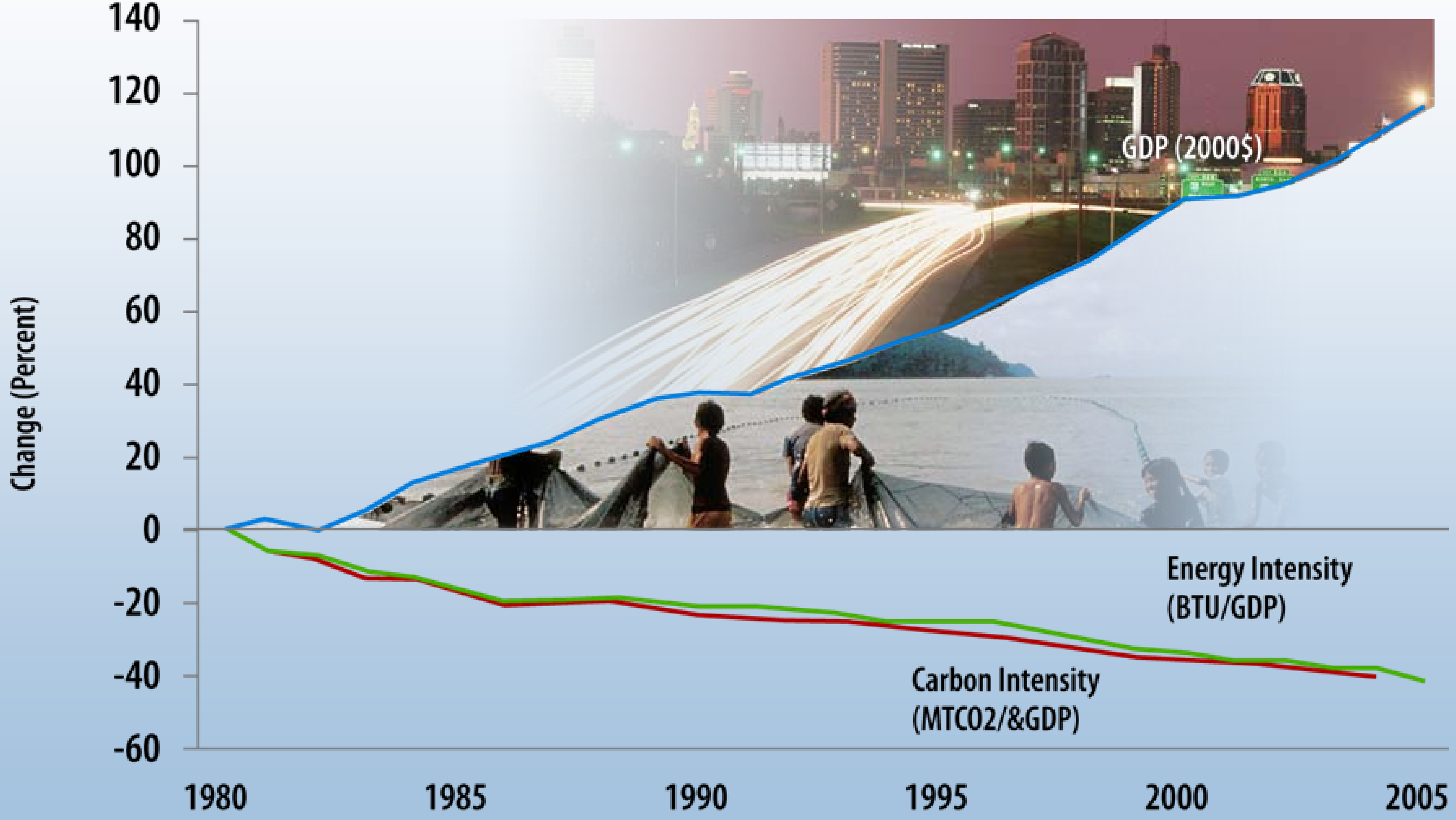
Source: OECD/IEA, 2004

U.S. Energy Consumption and the Role of Renewable Energy



Source: Energy Information Administration, *Annual Energy Outlook 2006,* Table D4

Carbon and Energy Intensity



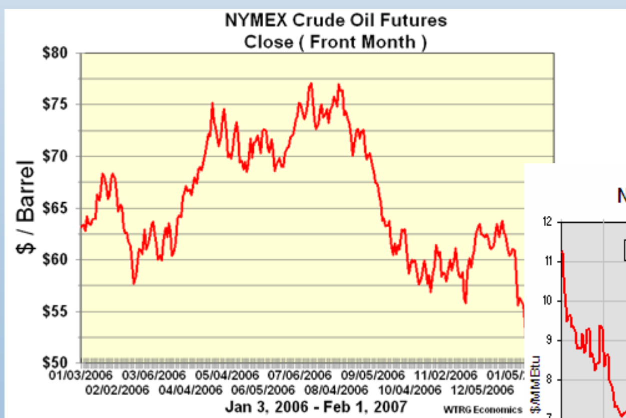
Source: Energy Information Administration, "Annual Energy Review 2005", DOE/EIA-0384(2005), Table 1.5

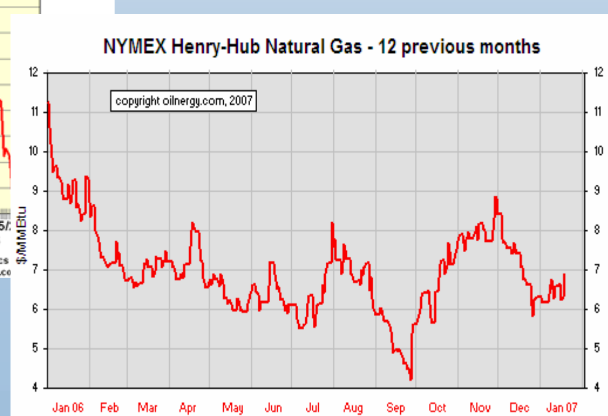
National Renewable Energy Laboratory

Thinking Differently
Account for Externalities

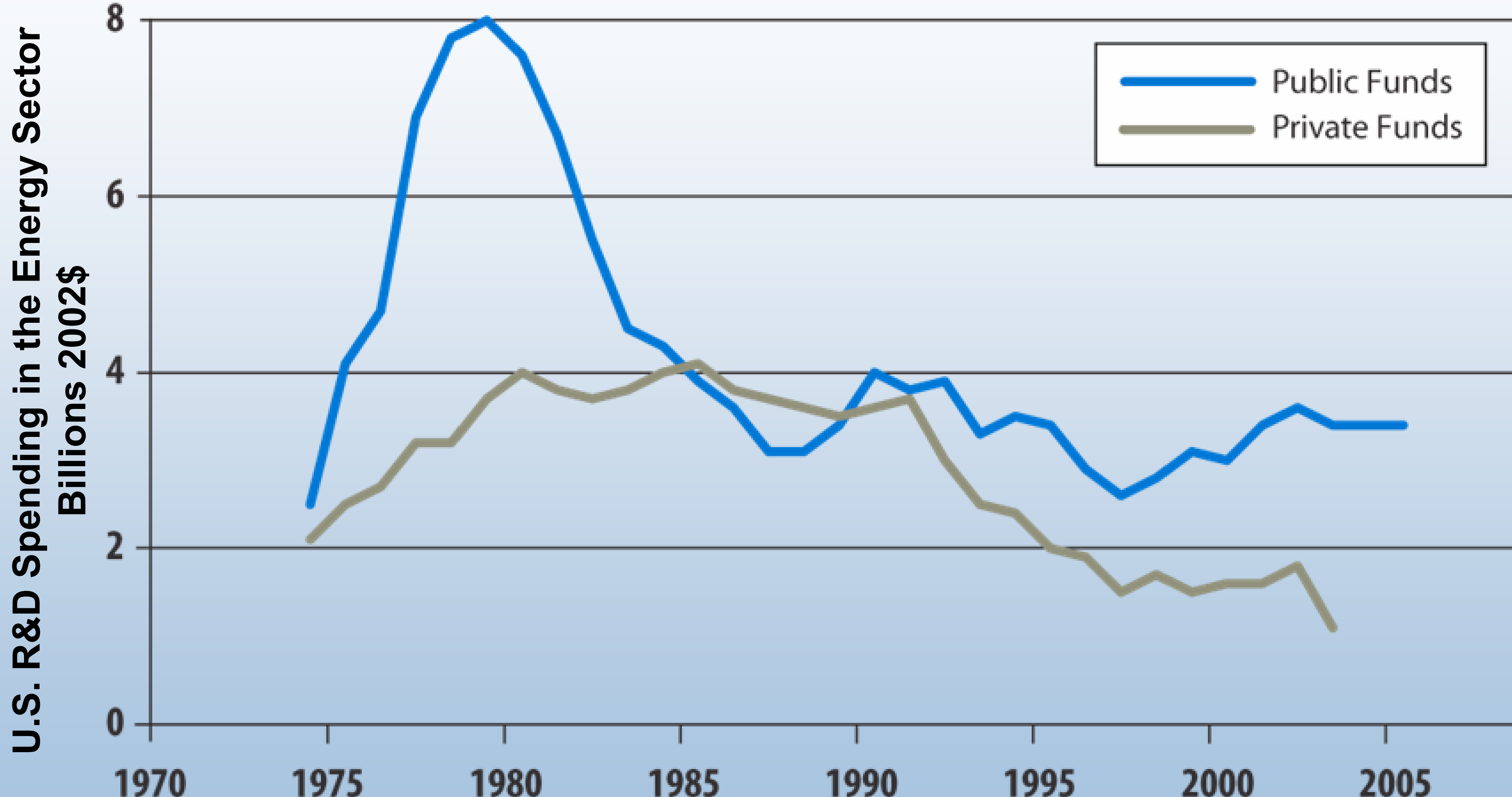
Today's energy marketplace does not appropriately "value" certain public objectives or social goods, instead we have:

- Price volatility
- Serious environmental impacts
- Underinvestment in energy innovation



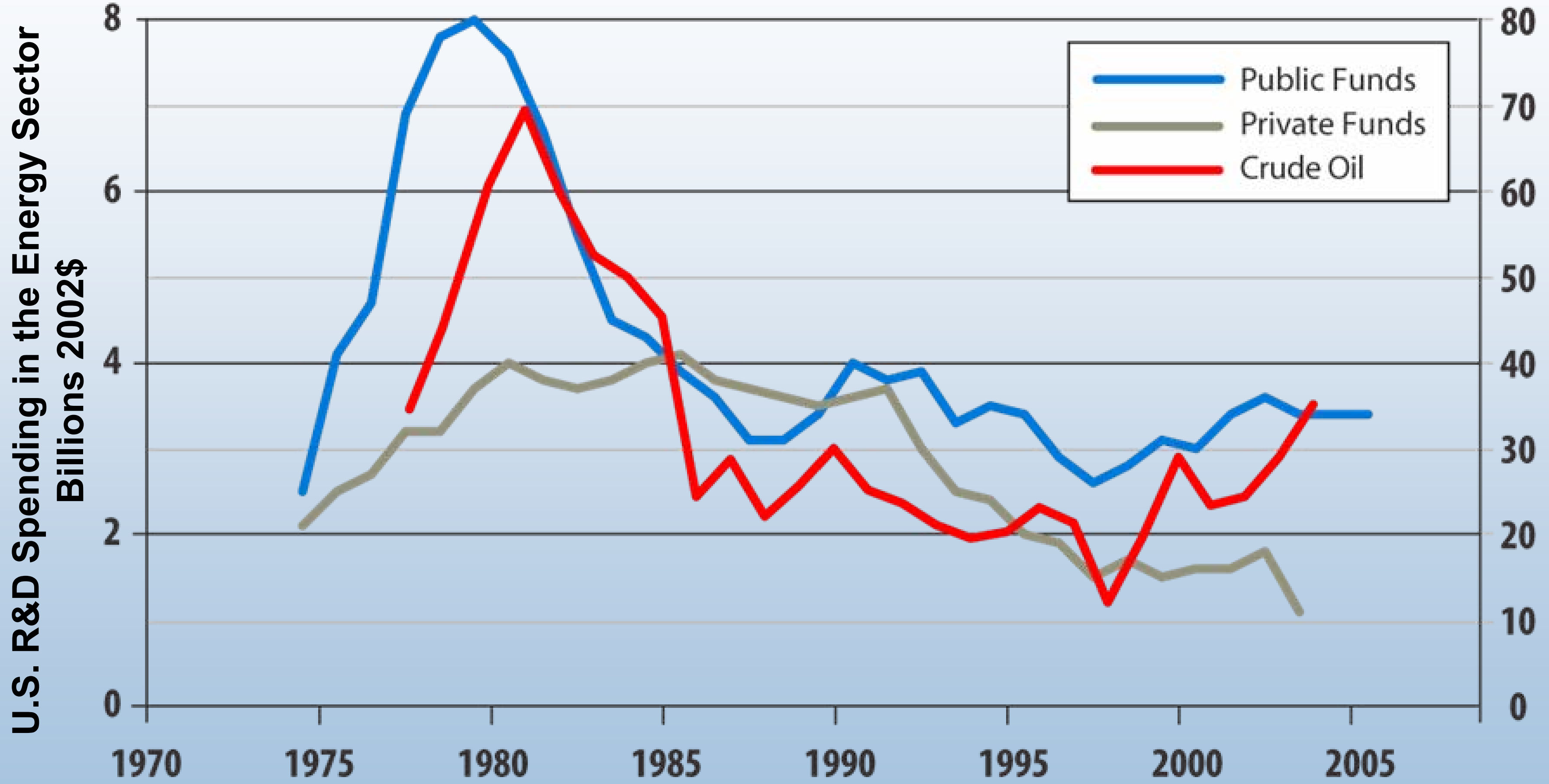


Declining Energy R&D Investments…



Source: Daniel Kammen, Gregory Nemet *Reversing the Incredible, Shrinking Energy R&D Budget* http://rael.berkeley.edu/files/2005/Kammen-Nemet-ShrinkingRD-2005.pdf
Table 10.3, Edition 25, *Transportation Energy Data Book* http://cta.ornl.gov/data/chapter10.shtml

Declining Energy R&D Investments… Reflect World Oil Price Movement



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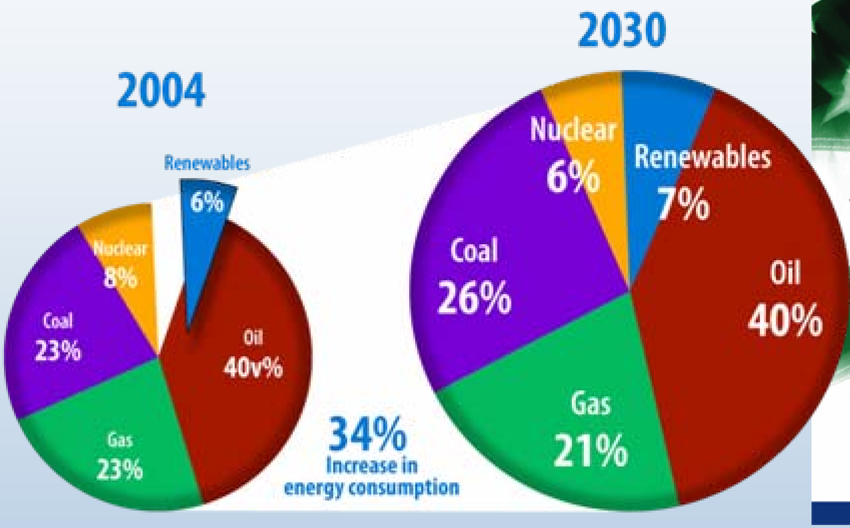
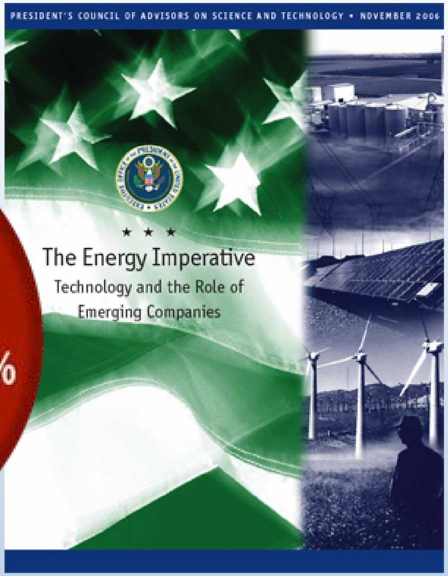
U.S. Energy Consumption and the Role of Renewable Energy





"…in the foreseeable future, the share of non-hydroelectric renewable electricity generation in the U.S. could grow to 10% or more by 2030 and to over 20% by midcentury."

PCAST Nov 2006

"Yes if" … not… "no because."

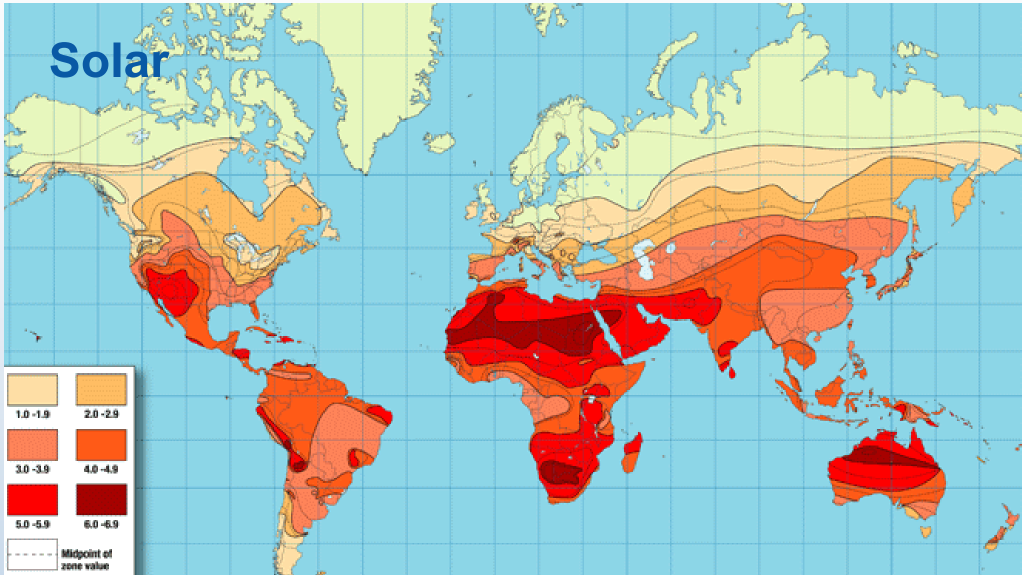
– Newt Gingrich

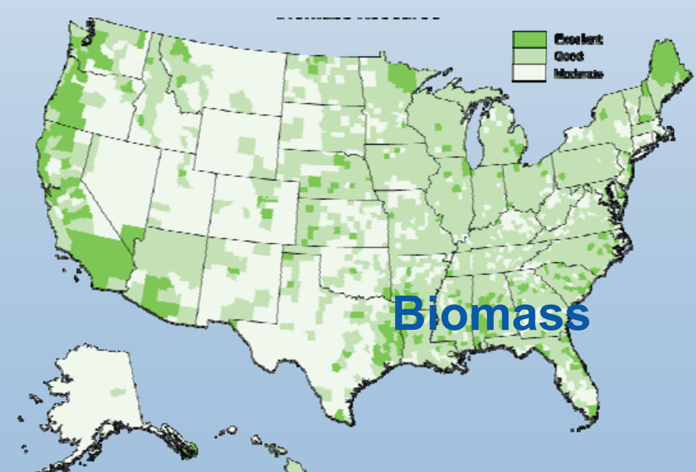
Source: OECD/IEA, 2004

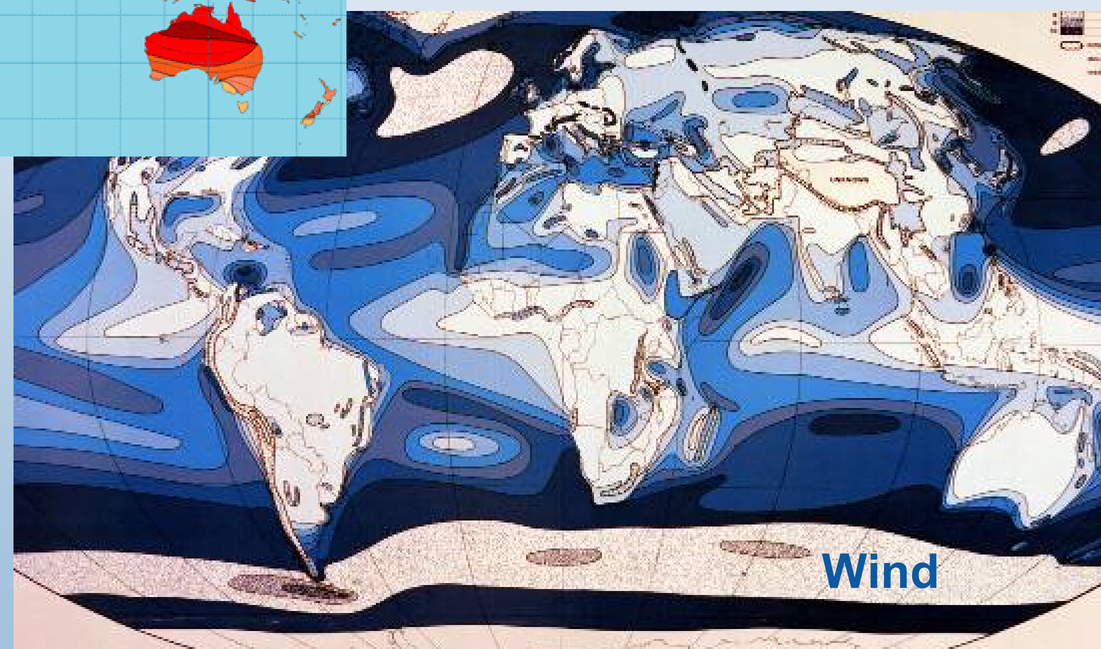
Technology-Based Solutions:
There is no single or simple answer

- Energy efficiency
- Renewable energy
- Nonpolluting transportation fuels
- Separation and sequestration of CO_2
- Next generation nuclear energy technologies
- Transition to distributed energy systems coupled with pollution-free energy carriers

Resources are Plentiful

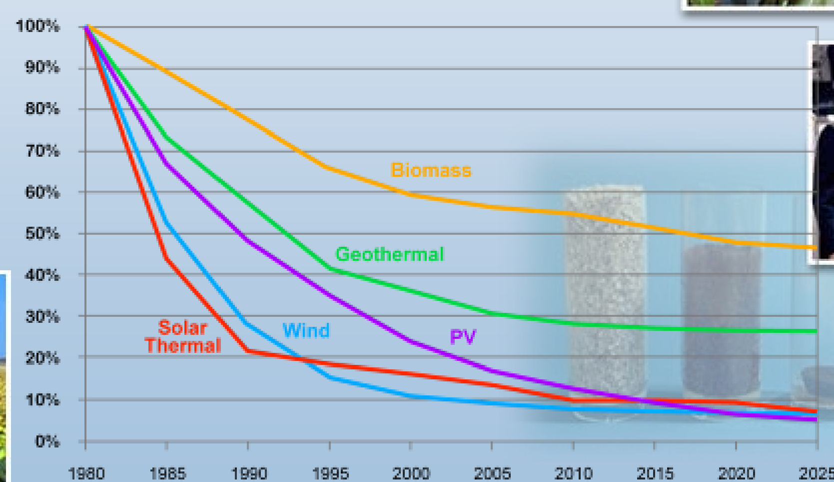




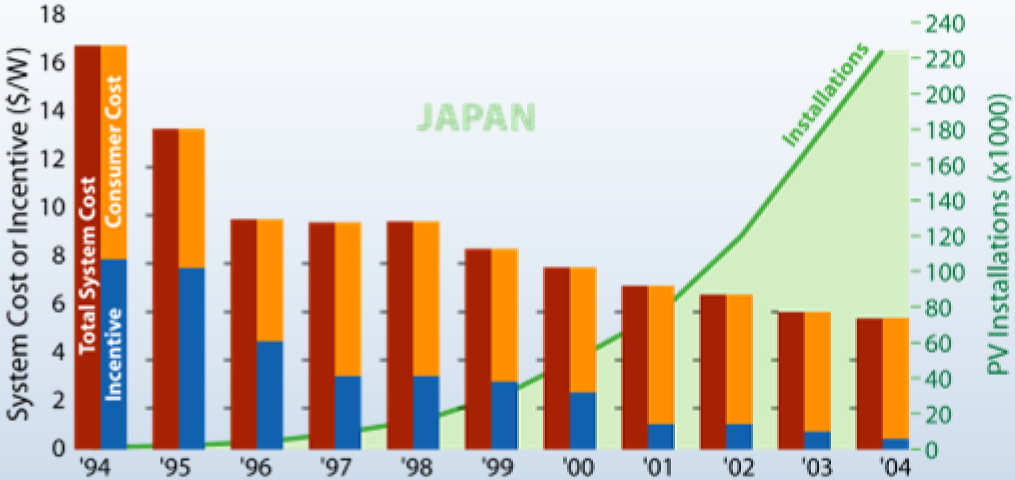


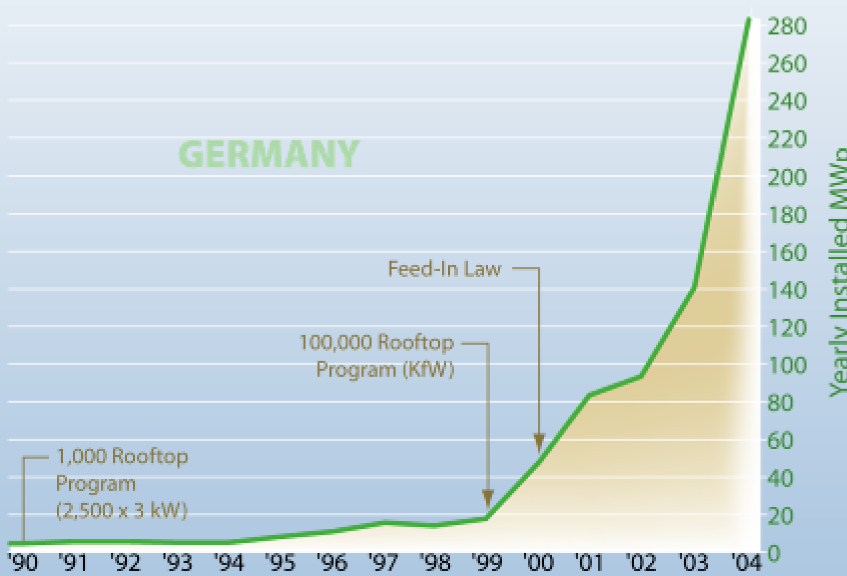
Source: http://howto.altenergystore.com/Reference-Materials/Solar-Insolation-Map-World/a43/
Pacific Northwest National Laboratory

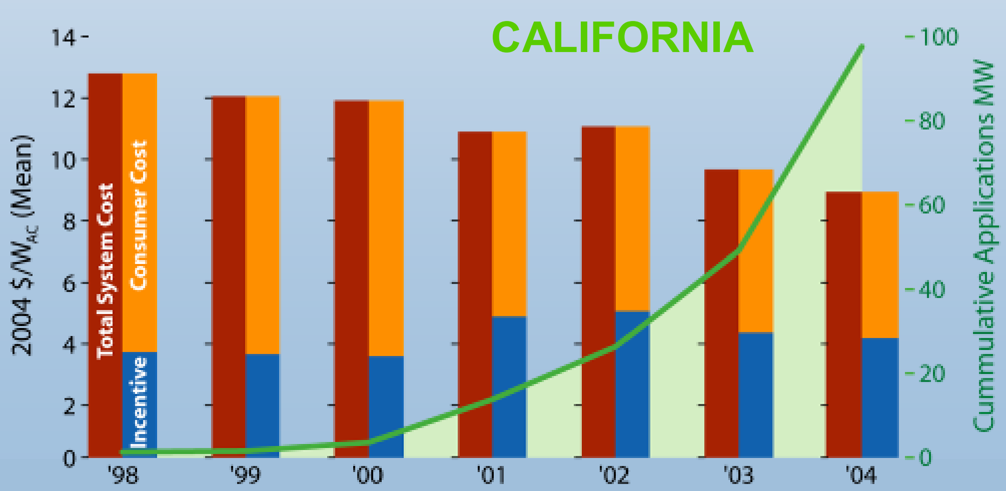
Impressive Cost Reductions



Worldwide Markets Have Driven Cost Reductions – Solar PV Example

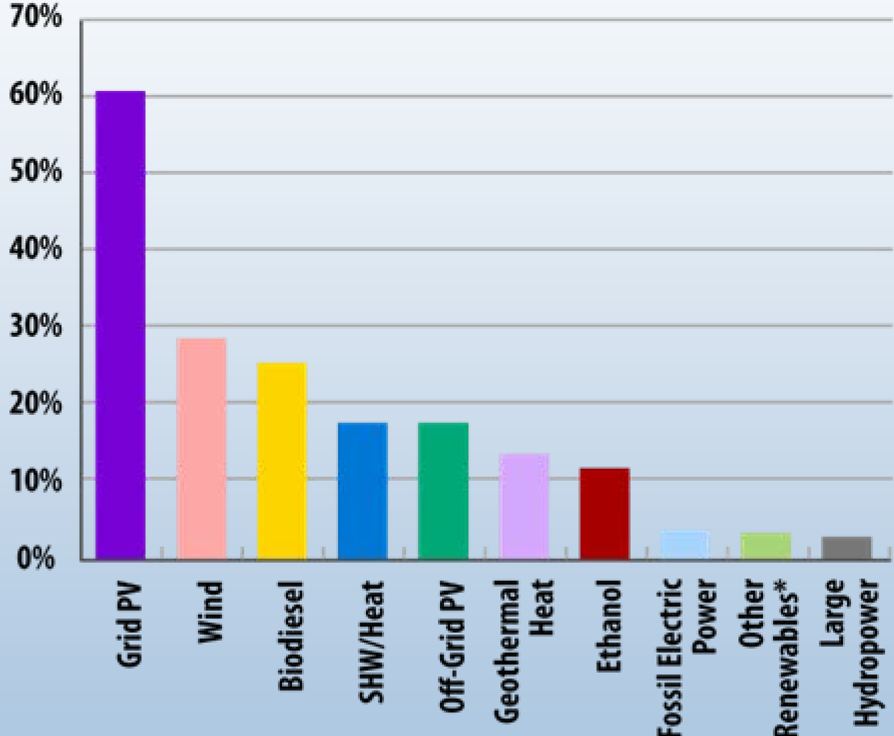




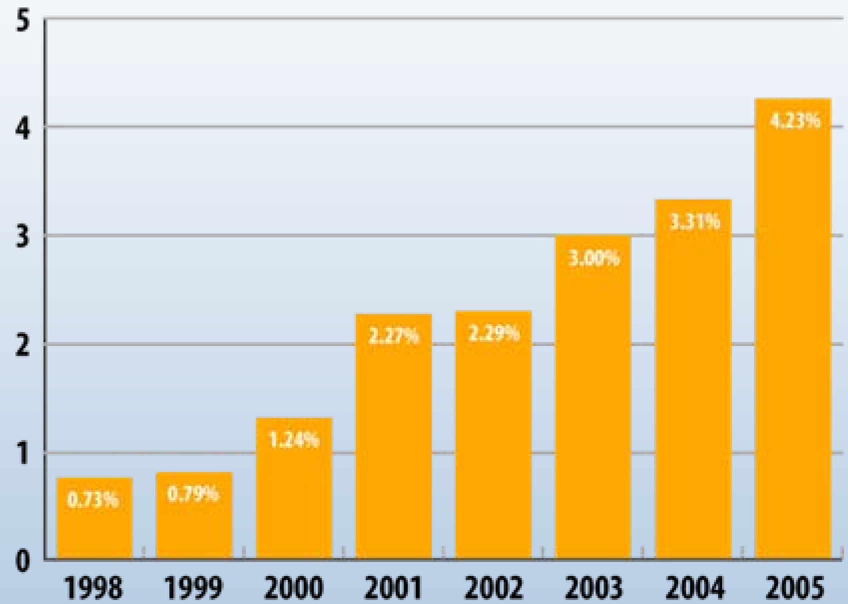


Investing in the Future

Global Renewable Energy Annual Growth Rates 2000-2004



Energy-Tech Investments Percent of Total U.S. Venture Capital



$2.7B invested in private clean energy firms in North America and Europe in 2006.

Sources:
Renewables 2005 Global Status Report, REN21
Clean Energy Trends 2006, Nth Power LLC
Venture Business Resources

Getting to "Significance" Involves…

Source: NREL

Consistent Policies are Required for Long-Term Market Growth

- National goals
  - Biofuels: 30% of gasoline by 2030
  - Wind: 20% of electricity generation by 2030
  - Solar: Be market competitive by 2015 for Solar PV
- Infrastructure investments required to meet these goals, for example:
  - Biofuels: 30x30 analysis estimated infrastructure cost between $8.5 and $28.5B over 23 years

NREL Energy Efficiency and Renewable Energy Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

- Wind
- Solar
- Biomass
- Geothermal

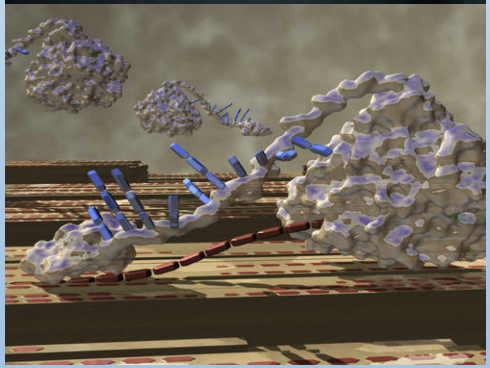
Energy Delivery and Storage

- Electricity Transmission and Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

Foundational Science

Technology Innovation Challenges

- Wind
  - Next generation wind turbines
    - Improve energy capture by 30%
    - Decrease capital costs by 25%
- Solar photovoltaics
  - Improved performance through
    - process improvements
    - better materials
    - concentration
  - Harnessing nanostructures & new quantum effects
- Biofuels
  - Next generation biofuels
    - New feedstocks
    - Improved energy crops
    - Integrated biorefineries



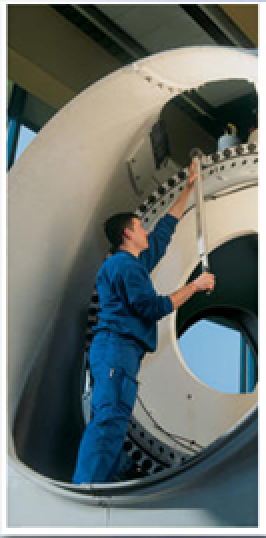
Wind

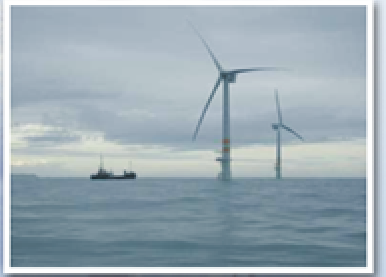
Today's Status in U.S.
- 11,603 MW installed at end of 2006
- Cost 6-9¢/kWh at good wind sites*

DOE Cost Goals
- 3.6¢/kWh, onshore at low wind sites by 2012
- 7¢/kWh, offshore in shallow water by 2014

Long Term Potential
- 20% of the nation's electricity supply

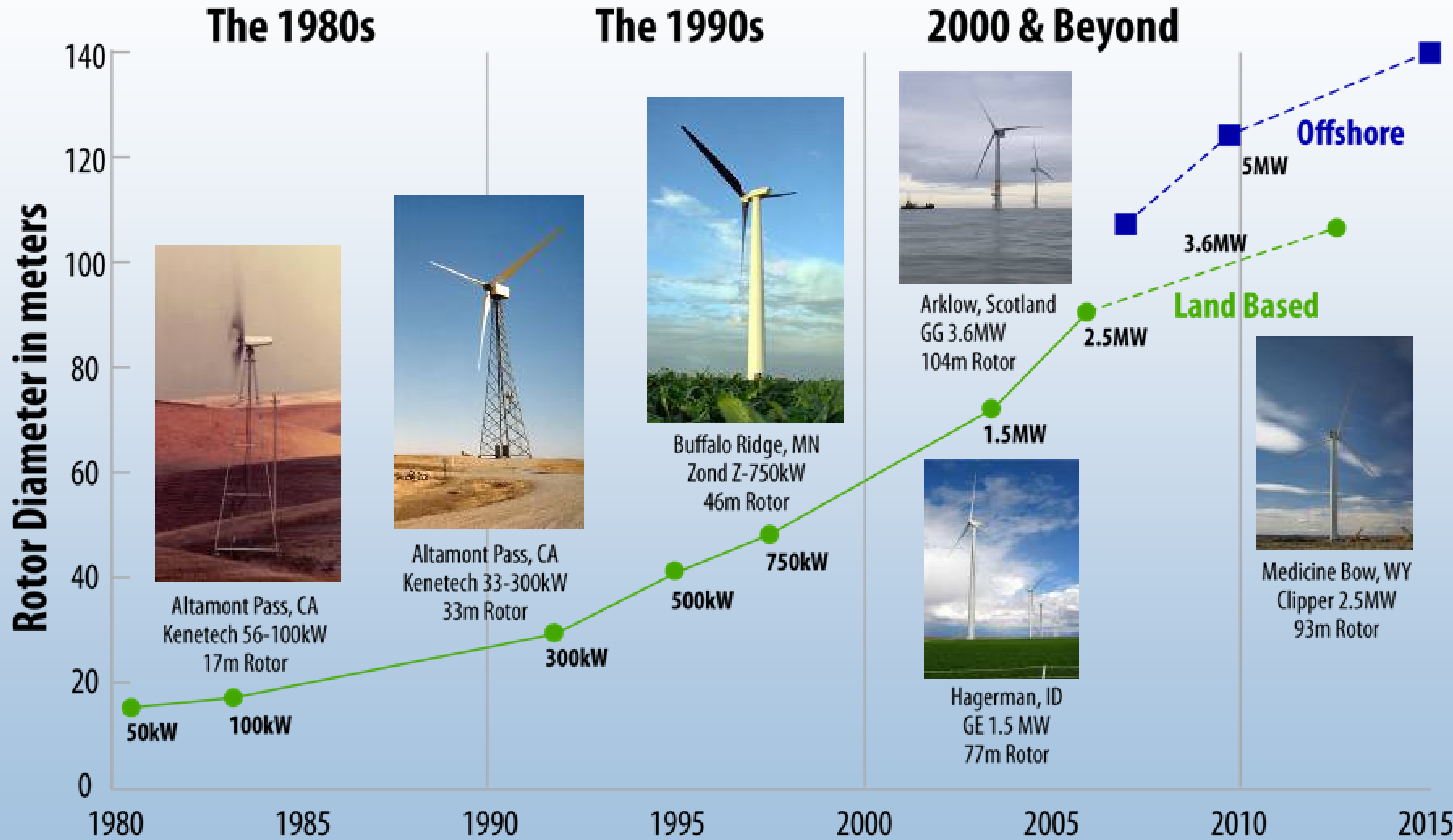
NREL Research Thrusts
- Improved performance and reliability
- Distributed wind technology
- Advanced rotor development
- Utility grid integration

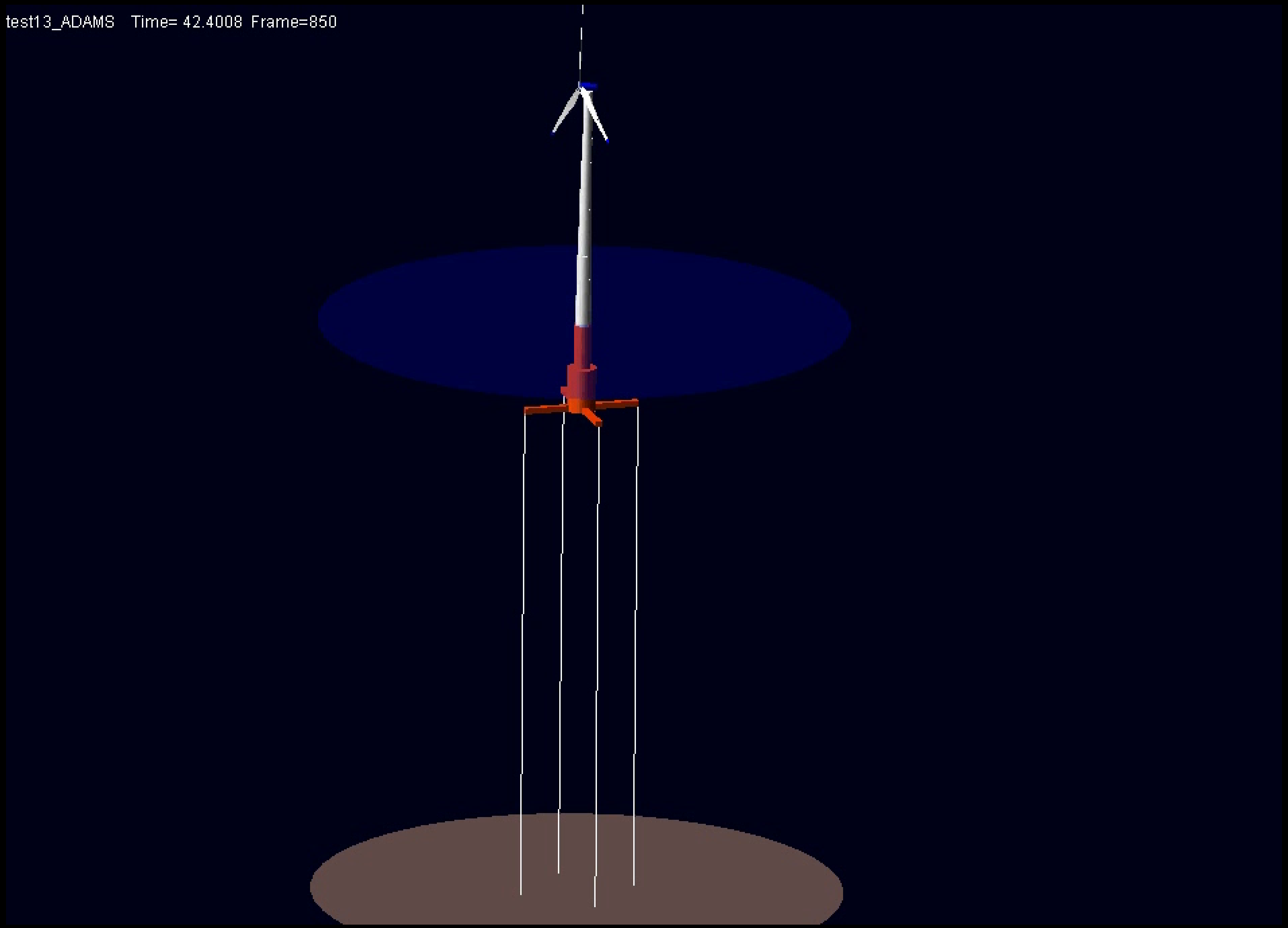




* With no Production Tax Credit
Updated January 23, 2007
Source: U.S. Department of Energy, American Wind Energy Association

Evolution of U.S. Commercial Wind Energy

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Solar

Photovoltaics and Concentrating Solar Power

Status in U.S.

PV

- 526 MW
- Cost 18-23¢/kWh

CSP

- 355 MW
- Cost 12¢/kWh

Potential:

PV

- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

CSP

8.5 ¢/kWh by 2010
6 ¢/kWh by 2015

NREL Research Thrusts:

PV

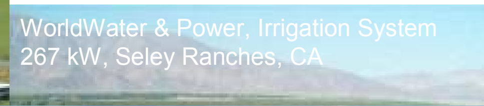
- Partnering with industry
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

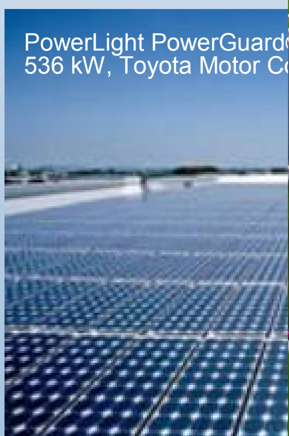
CSP

- Next generation solar collectors
- High performance storage

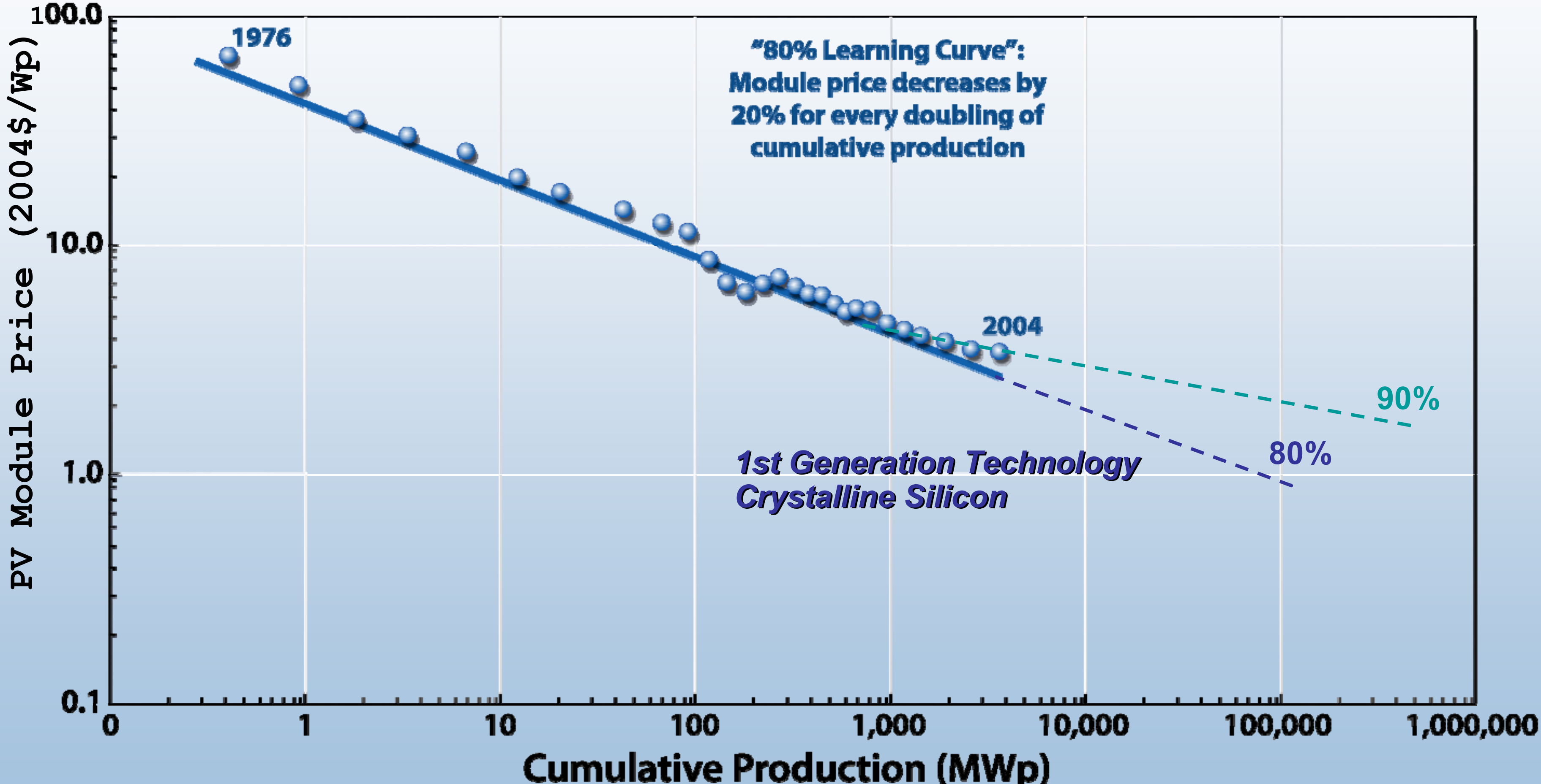
Source: U.S. Department of Energy, IEA
Updated November 8, 2006

…toward our destination

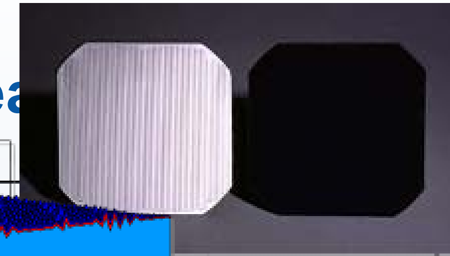


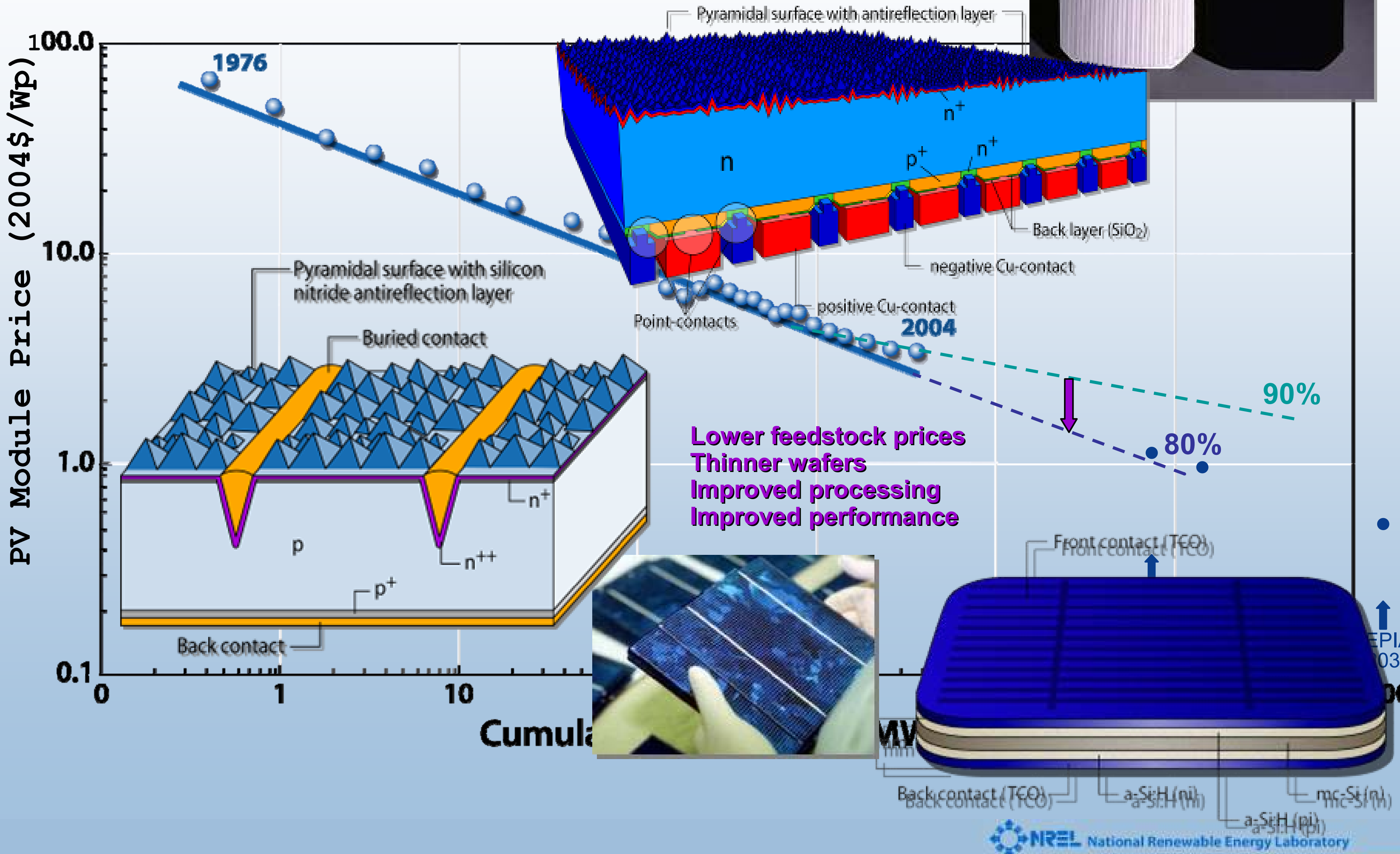


PV Module Production Experience (or "Learning") Curve

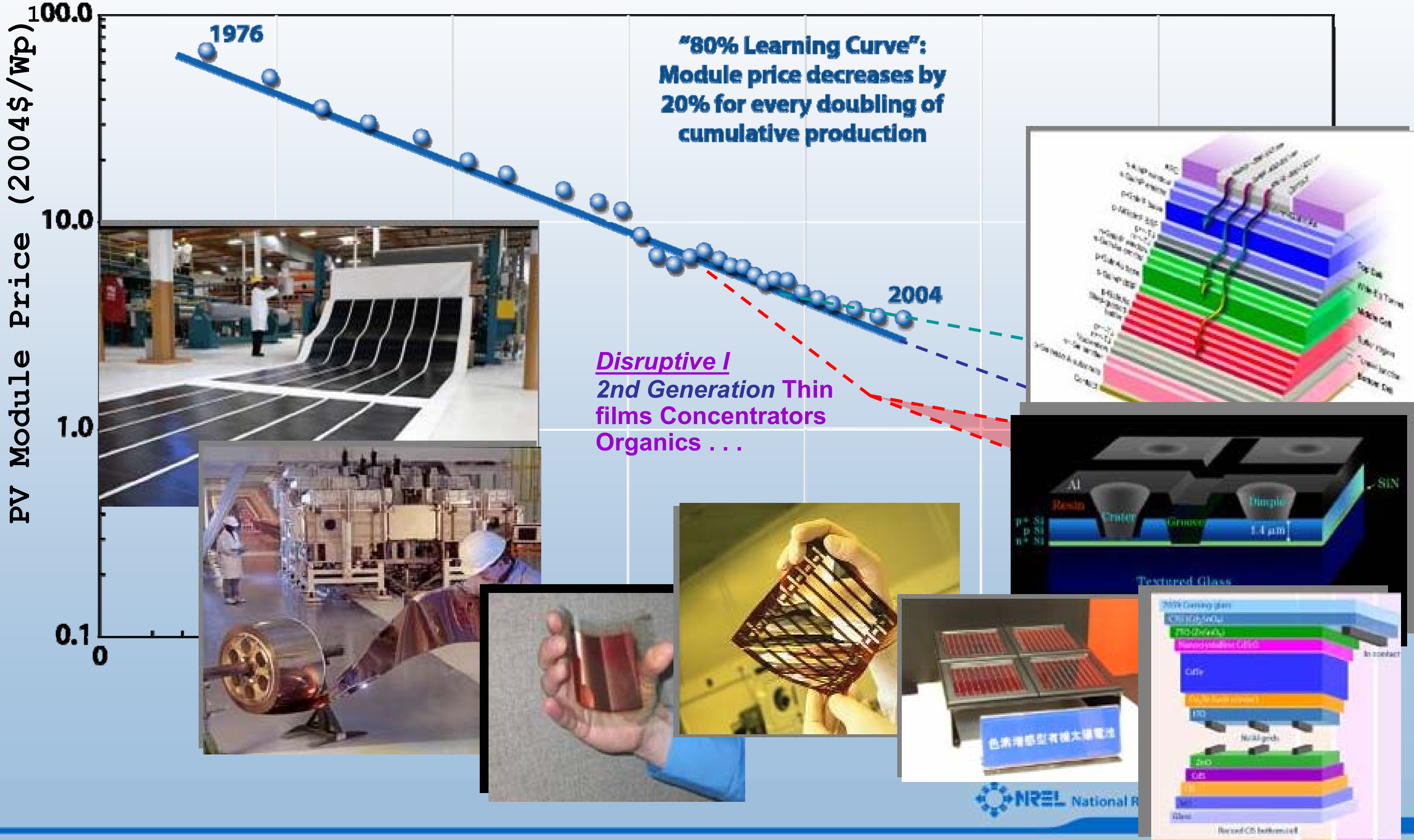


PV Module Production Experience (or “Lea





PV Module Production Experience (or "Learning") Curve

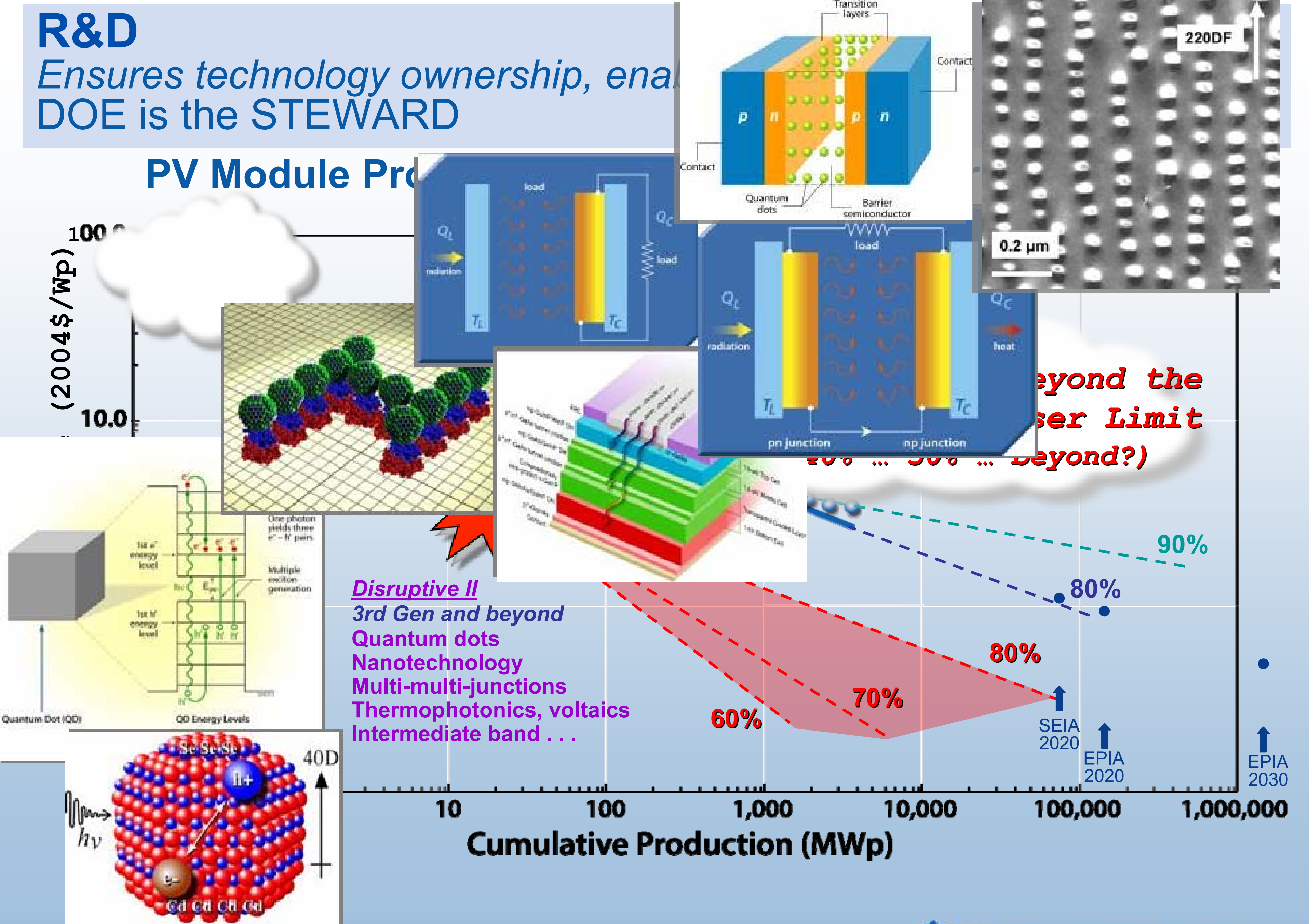


R&D

Ensures technology ownership, ena

DOE is the STEWARD

PV Module Pr



Technology Investment Pathways

Industry Driven

1st & 2nd Generation PV

lower Si feedstock prices
thinner Si wafer technology
thin films
improved processing
improved performance
advanced integration
advanced packaging

Basic Research Driven

3rd Generation PV

quantum dots
nanotechnology
multi-multijunctions
thermophotonics
intermediate band
bio-inspired

Technology Driven

2nd Generation PV

thin films
concentrators
organics
Si wafers <100 μm
Si cells beyond 25%

The New Biofuels
President Bush's *"Twenty in Ten: Strengthening America's Energy Security"*

- Reduce U.S. gasoline consumption 20% by 2017
  - Require 35 billion gallons of renewable and alternative fuels by 2017 to displace 15% of projected annual gasoline use
- President's 2008 Budget will
  - Include nearly $2.7B for the Advanced Energy Initiative, an increase of 26% above the 2007 request
  - Provide $179M for the President's Biofuels Initative, an increase of $29M (19%) compared to the 2007 budget
- President's Farm Bill proposal will include more than $1.6B of additional new funding over ten years for energy innovation, including bioenergy research and $2B in loans for cellulosic ethanol plants

Biofuels

Current Biofuels status

- Biodiesel – 91 million gallons[1] (2005)
- Corn ethanol (Nov. 2006)
  - 106 commercial plants[2]
  - 5.1 billion gallon/yr. capacity[2]
  - 3rd Q 2006 rack price highly variable \$3.50 – 5.50/gallon of gasoline equivalent (gge)[3]
- Cellulosic ethanol
  - Projected commercial cost ~\$3.50/gge

Key DOE Goals

- 2012 goal: cellulosic ethanol ~\$1.62/gge
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

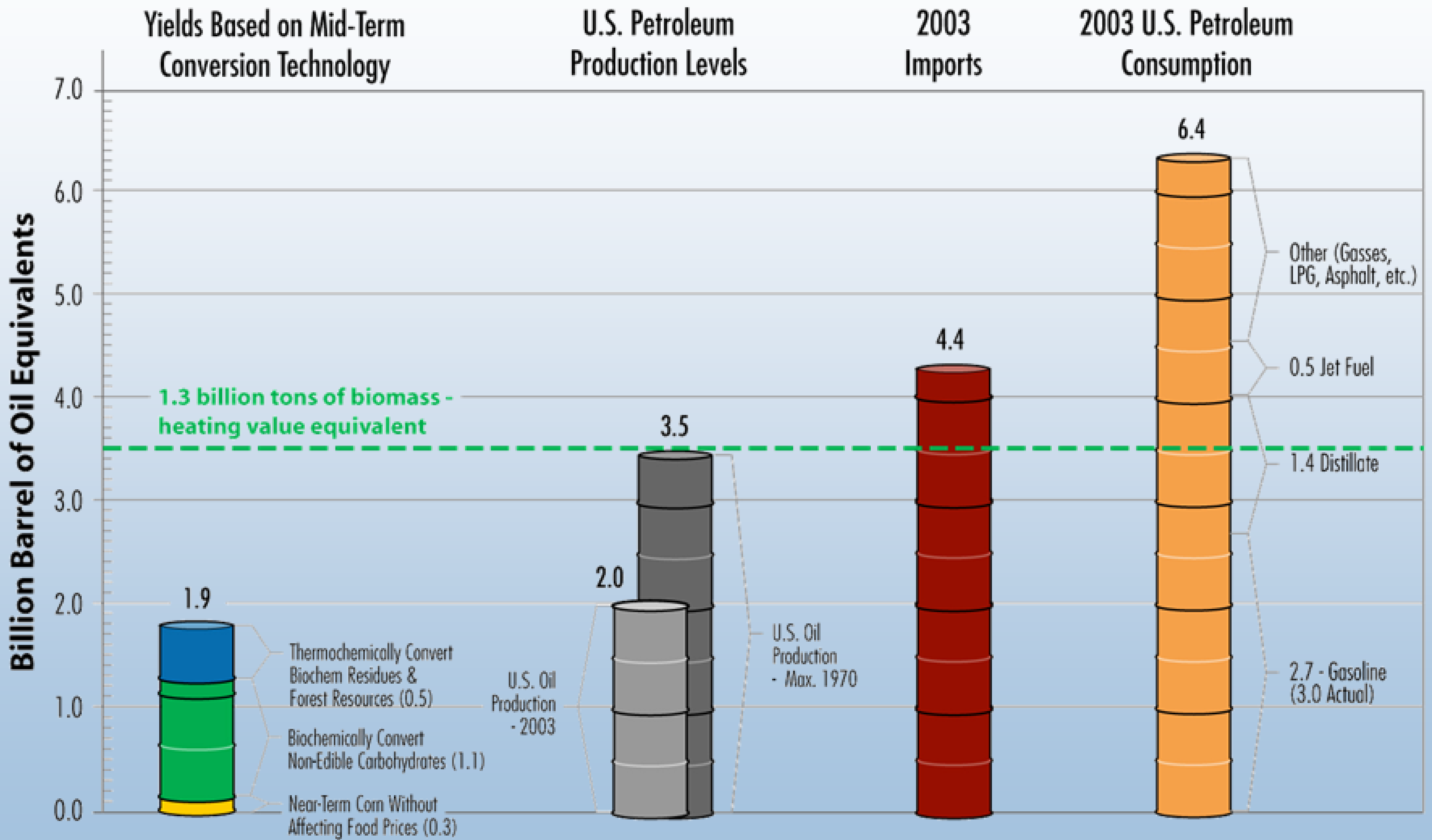
NREL Research Thrusts

- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops

Updated November 10, 2006

Sources: 1- National Biodiesel Board, 2 - Renewable Fuels Association, 3 – American Coalition for Ethanol, all other information based on DOE and USDA sources

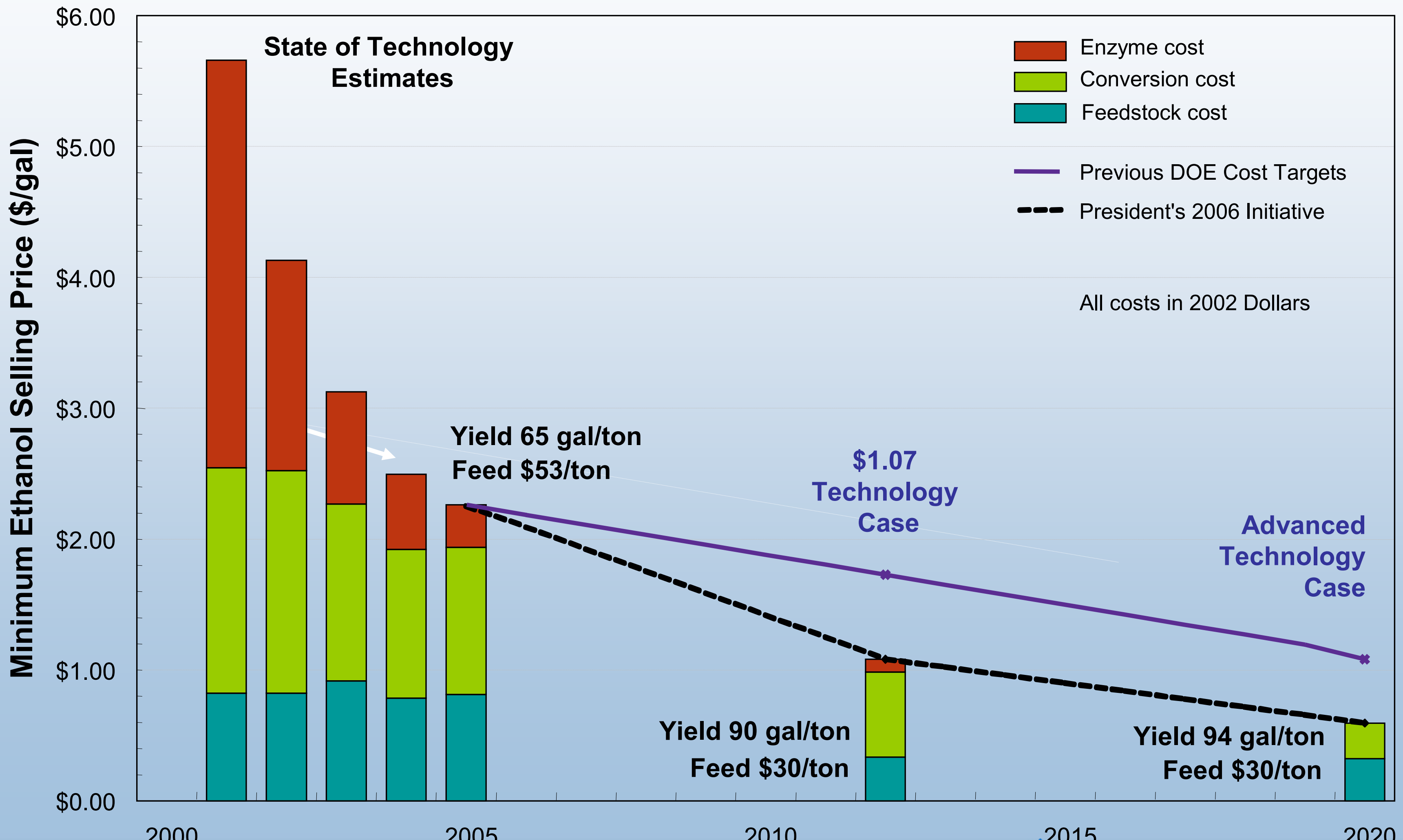
Significance of the 1.3 Billion Ton Biomass Scenario



Based on ORNL & USDA Resource Assessment Study by Perlach et.al. (April 2005)
http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf

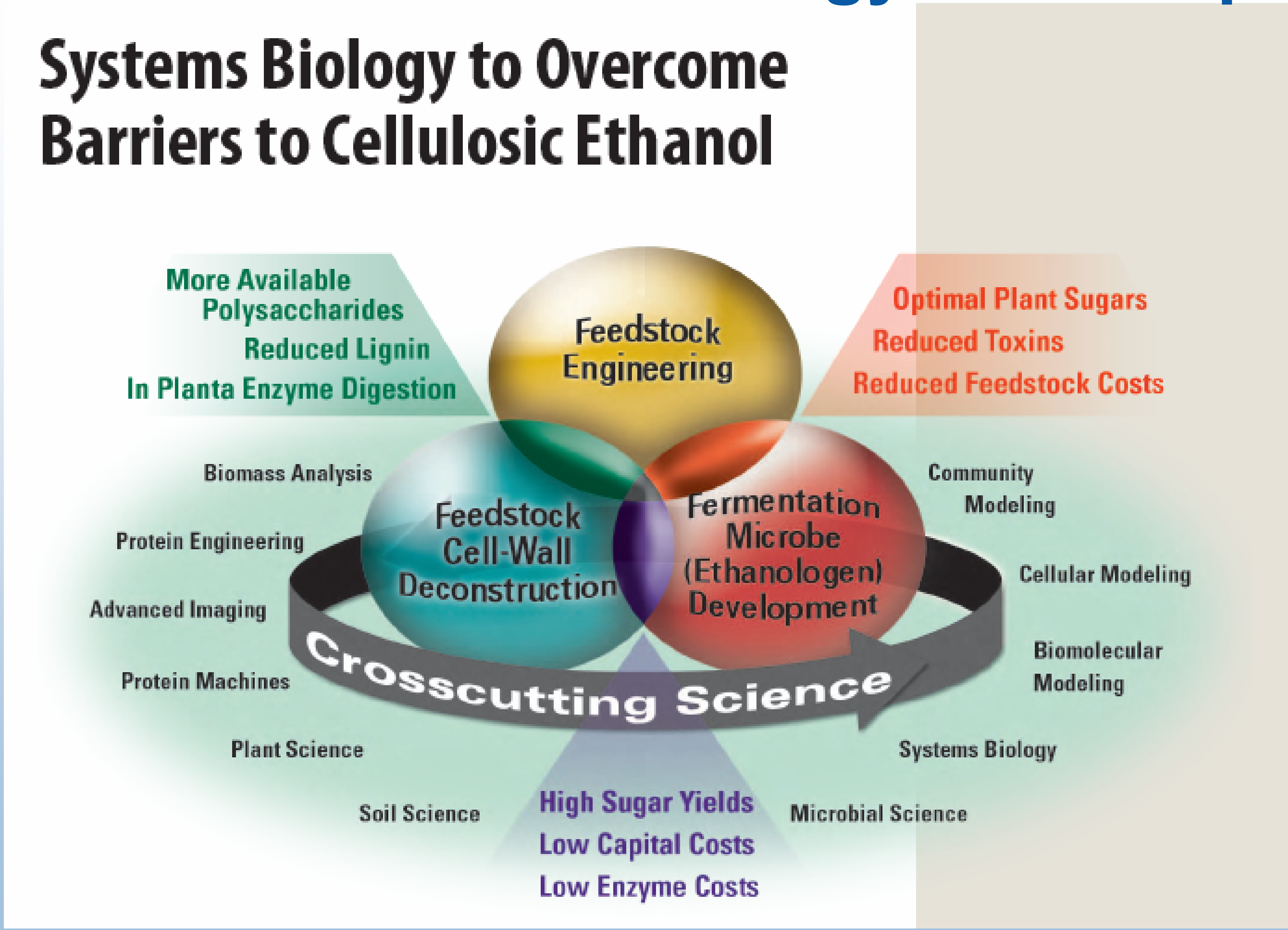
National Renewable Energy Laboratory

Reducing the Cost of Cellulosic Ethanol



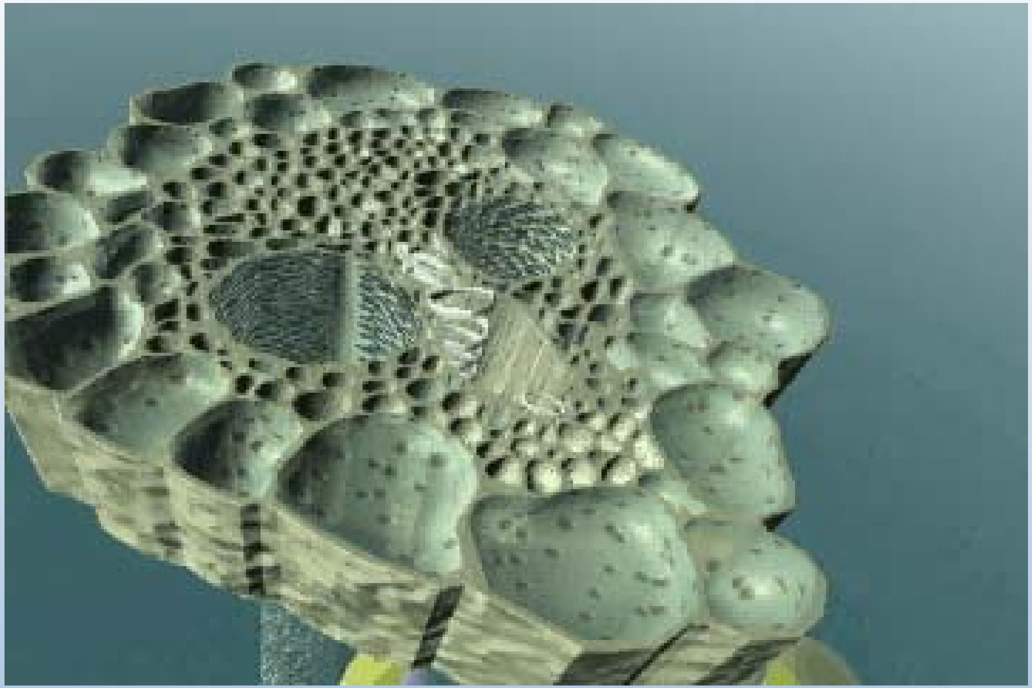
NREL National Renewable Energy Laboratory

From DOE GTL Bioenergy Roadmap



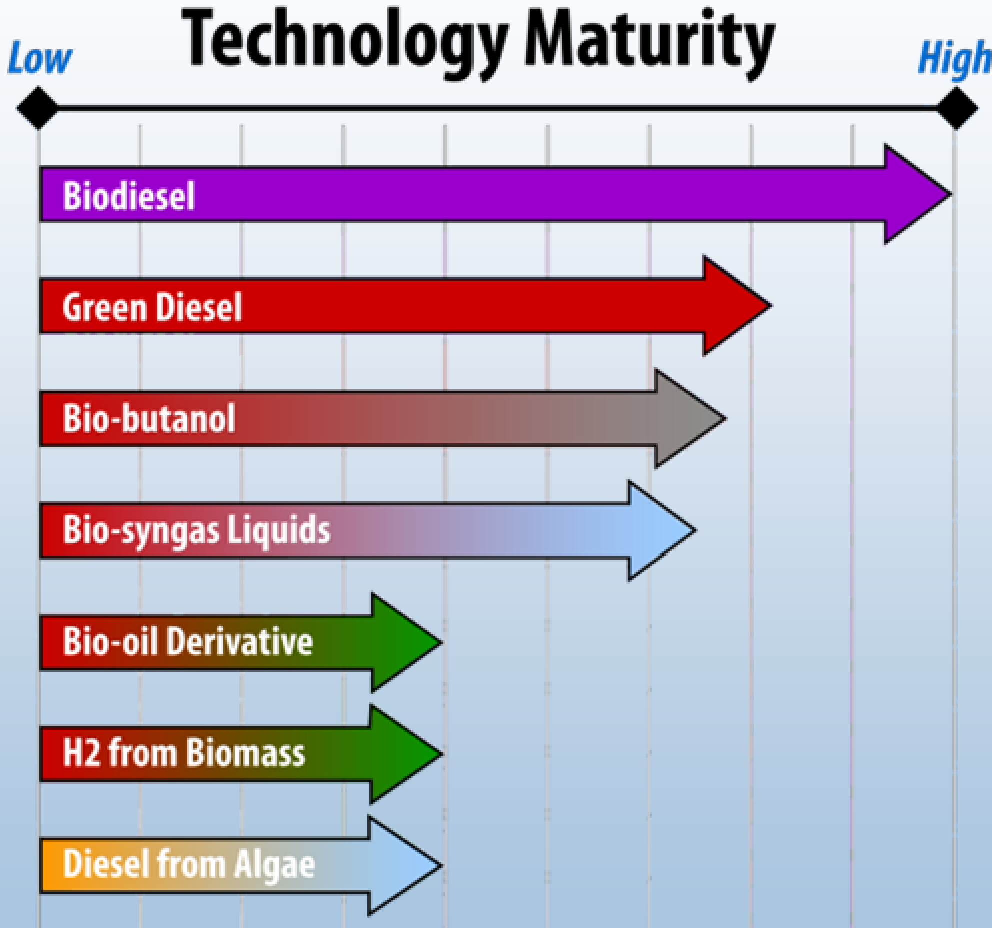
Feedstock Engineering

- Increase crop production (agronomics and plant engineering)
- Increase composition of desirable polysaccharides (cellulose)
- Decrease composition of undesirable polymers (lignins)



NREL "Corn Stem Tour"

Biofuels R&D



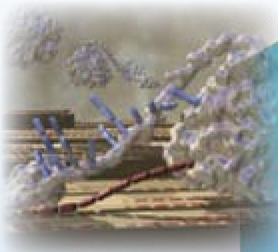
Key Drivers	Value Added
New market for excess oils, fats, and greases.	Petroleum compatible and biodegradable.
Lower cost and higher product quality than FAME.	Utilize existing assets. High quality jet fuel or diesel.
New market for grain and agriculture products. Large supply of lignocellulose.	Better gasoline blending properties than ethanol.
Integration of biomass with Coal, Coke, Shale, or Heavy Oils.	High quality jet fuel or diesel. Reduced criteria for sequestration, and economy of scale (in combination with fossil).
Technical fit with woody biomass and liquid bio-crude.	Potential to integrate into existing large scale refinery and pipeline infrastructure.
Potential transportation fuel from any fuel/power source.	Ideal feed for fuel cells, and lowest tail pipe emissions.
Lg. source of biomass on non-arable land, and capture of CO^2.	High quality jet fuel or diesel yield per acre, with both off-shore and on-shore potential.

Renewable Fuels & Low GHG Emissions

Organizations Leading the R&D

- Grain/Agriculture
- Coal
- Chemical
- Petroleum
- Forestry
- Academia & Startups

Technology Investment Pathways
Renewable Fuels



Basic Research Driven

Deep Understanding

- Systems biology & HTP
- Structural biology
- Computational science
- Biomass ultrastructure
- Advanced imaging tools
- Photosystem biochemistry
- Enzyme engineering
- Photoelectrochemistry

Revolutionary
(10 years and beyond)

30X30 Report
OSC/EE Workshop on Cellulosic Ethanol
IBRF Upgrade

Accelerated Evolutionary
(3 years)

Disruptive
(3–10 years)

Industry Driven

Transportation Fuels

- Bioethanol pilot plant
- Technoeconomic analysis
- Performance testing for industry
- Biofuel cells
- Rapid biomass analysis
- Process unit testing

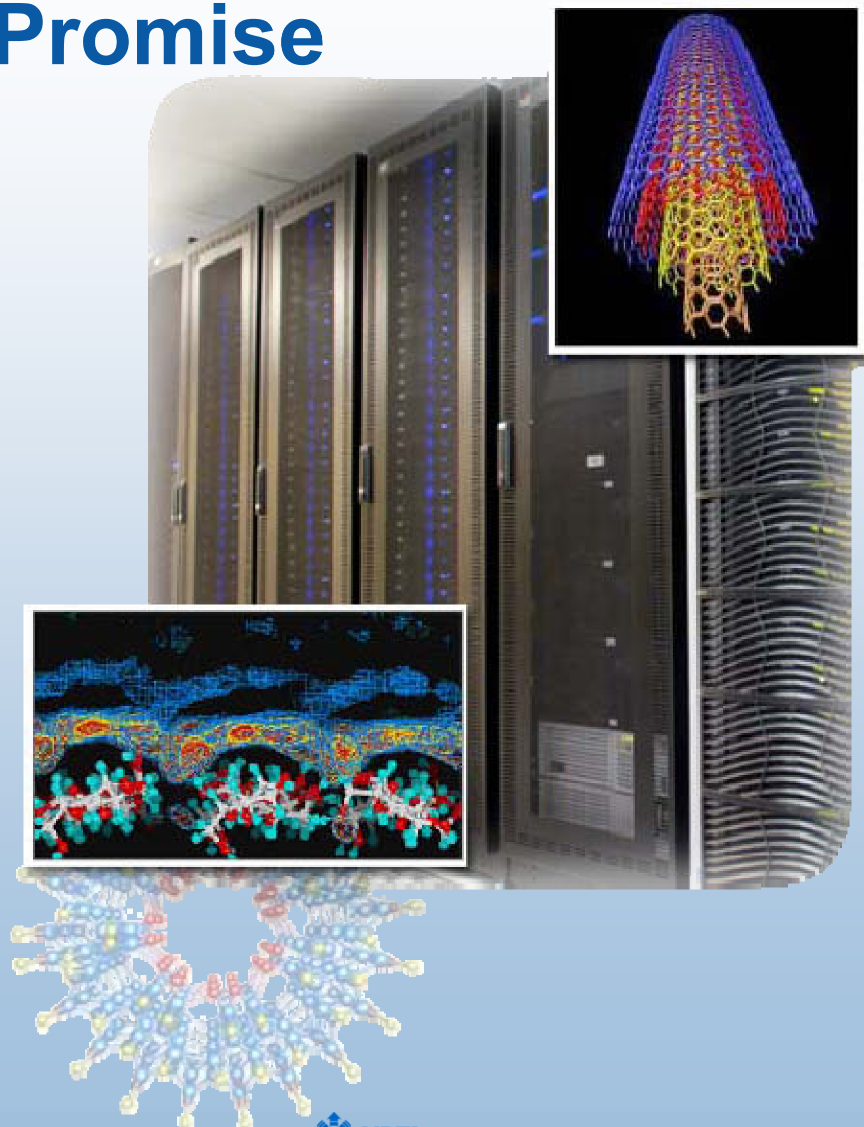
Technology Driven

Translational S&T

- Process consolidation
- Biological hydrogen
- Photoelectrochemical hydrogen
- Biomass pretreatments
- Mapping the plant cell wall
- Plant delignification
- Chemistry of biomass toxins

Harnessing Innovation in Renewable Energy Science and Technology: The Future Promise

- Supercomputers
- Genomics
- Nanoscience
- Cellulosic and biofuels applications
- Hydrogen



Nano/Bio/Info

Putting the Pieces Together

Promise of renewable energy is profound and can be realized if we…

- Aggressively seek a global sustainable energy economy
- Acknowledge and mitigate the carbon challenge with the necessary policies
- Accelerate investment in technology innovation

It is a matter of national will and leadership